



**Improving and conserving sahelian fruits trees
a case study of *Parkia biglobosa* (Jacq.) Benth**

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Moussa Ouedraogo

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Improving and conserving sahelian fruits trees: a case study of *Parkia* *biglobosa* (Jacq.) Benth

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Dedication

I dedicate this thesis to :

- my late father Issou Ouedraogo named Pondo, whose love of Mango grafting was inspiring and gave me this passion in tree domestication.
- my late adopted mother Alimata Ouedraogo named Kèma, whose careful and lovely guidance during my childhood was an inexhaustible source of wisdom and combativeness.
- my late mother Mariam Barry, who passed away during the period of my PhD work, rest in peace dear mum.

May God bless them.

Aknowlegement

This thesis is about management of genetic resources of the West African fruit tree species, *Parkia biglobosa*. It is a result of the cooperation between Burkina Faso National Tree Seed Centre and West African National Research Institutes and Forest Administrations which are currently working for forest genetic resources conservation and valuation. These institutes were involved in *P. biglobosa* germplasm collections in 1994. In this respect, I'm grateful to them.

The present thesis will not be a reality without these collections which lead to the establishment of two (2) "historical" provenances trials in Burkina Faso. From these trials, significant knowledge of the genetic potentials of *P. biglobosa* has been drawn.

This work is also a fruitful cooperation between Forest and Landscape/ University of Copenhagen / Denmark and Burkina Faso National Forest Seed Centre which cooperated for the implementation of Sahelian Fruit Trees (SAFRUIT) project.

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Gambo, Yatenga Province,
Burkina Faso, January 2014

Moussa Ouedraogo

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ABSTRACT

Despite their economic value and their nutritional importance, indigenous fruit trees in the Sahel are decreasing as the parklands are rapidly degrading these last 20 to 30 years. This is due mainly to demographic pressure and climate variability characterized by drought that is occurring with increasing frequency and intensity. Tree improvement which could lead to adapted and productive genetic material for the farmers is viewed as one solution to tackle this problem and to improve the local population's livelihoods through the increase of tree production.

In spite of the importance of tree improvement programmes, they are still in their infancy in developing countries particularly for the Sudano Sahelian Africa. Since the 1960s, sporadic activities have been initiated in the countries but substantial improvement programmes are yet to be launched.

In 2005 a cooperative research project which involved 3 European universities (University of Bangor United Kingdom, University of Wageningen, Netherlands, and University of Copenhagen, Denmark) and 4 national research institution in the region (from Mali, Niger, and Burkina Faso) was initiated in order to contribute to local populations livelihoods in the sahelian region through improvement and conservation of the four most important Sahelian fruit trees species (*Tamarindus indica*, *Adansonia digitata*, *Ziziphus mauritiana* and *Parkia biglobosa*). More specifically, the objective of the project was to deepen the genetic knowledge base on the above four species in relation to management and conservation of their genetic resources.

The present thesis is about breeding and conservation of *Parkia biglobosa* which is well known for its socio-economic importance. It addresses four aspects:

- The study of performances of provenances in old trials;
- The investigation of the genetic structure of *P. biglobosa* in its natural range in West and Central Africa through leaf morphology and molecular markers studies;
- The investigation of the *P. biglobosa*' phenology in provenances trial;
- An approach for *P. biglobosa* genetic resources utilisation and conservation strategy in Burkina Faso.

The study of the provenances performances is based on analysis of survival and growth traits in two international provenances trials located in the north Sudanian zone (Gonsé) and south Sudanian zone (Dinderesso) in Burkina Faso. Evidence of substantial genetic differentiation between the 25 populations within West Africa is provided. Hypothesis of the presence of a continuum of locally adapted populations has been given to explain the species ability to thrive under quite different climatic conditions across West Africa. Recommendations for seed deployment and conservation strategies of the species in West Africa were also suggested.

The genetic structure of *P. biglobosa* was analysed through studies of leaf morphological traits, and chloroplast microsatellites test of 25 provenances. Significant clinal variation relating to longitudinal origin was found for six of the studied leaf morphological traits.

The DNA sequence analysis revealed a strong phylogeographical structuring with the seven identified haplotypes being divided into an eastern and a western group. The haplotype network indicated that the species originated or had a refugium in central West Africa. From the joint analysis of morphological and neutral markers of genetic variation, vicariance as the source of the observed variation in the species was suggested. The strong geographic affiliation of the haplotypes suggests

that humans have played only a minor role in forming the present day distribution of the species. It is speculated that past climate regime of the region could explain the leaf morphological variation observed in the species.

The phenological investigation of the *P. biglobosa* in provenances trial aimed to study how the provenances behave under the south Sudanian conditions in Burkina Faso. The phenology study confirmed that significant genetic variation exist among the provenances of *Parkia biglobosa* in flushing, flowering and fruiting traits and careful choice has to be made when selecting the provenances for tree seed orchards establishment for example.

The genetic resources utilisation and conservation strategy of *P. biglobosa* in Burkina Faso was initiated through the species germplasm collection and BSO establishment. The germplasm collection was undertaken through plus trees selection and a progeny test was initiated to deepen the genetic study of the species and furthermore to estimate genetic parameters which are important steps for the species' breeding activities. Tree-to-tree variation in fruit traits and seed traits were highly significant suggesting that substantial genetic gain could be obtained by selecting for superior trees. Significant correlations were also found between fruit traits and seed traits indicating that indirect selection for seed production could be done based on the fruits traits (pod morphological traits). Even at early age, significant difference was found among open pollinated families in seedling height and in collar diameter with families from more humid zones having faster growth rate.

The present findings on the species' genetic diversity, its genetic structure in natural populations and the genetic gains that can be obtained through selection and breeding constitutes a good start to strengthen the species tree improvement programme. The strategy proposed for seed deployment and for the development of the breeding zones in Burkina Faso may lead to a better utilization and conservation of the species' genetic potential. The principles of this approach could be extended to the regional level as the Sahelian countries are experiencing the same climatic conditions.

DANISH RESUME

Lokale frugttrearter er af meget stor værdi for befolkningerne i Sahelområdet, men i løbet af de seneste årtier er sket en løbende reduktion i antallet af træer for mange af disse arter.

Udvalg og forædling af træer med god tilpasning og produktion er vigtig for at sikre træernes fortsatte tilpasning, og samtidig øge deres produktion til fordel for lokale befolkninger livsgrundlag. Til trods herfor er der hidtil kun foretaget en meget beskeden indsats vedrørende forædling af de lokale frugttrearter, og siden 1960'erne har der kun været sporadiske studier af arternes genetiske ressourcer. Egentlige forædlingsprogrammer er stadig manglende.

I 2005 begyndte et samarbejdsprojekt (SAFRUIT) om domesticering af lokale frugttre i området. Partnere fra Europa var University of Bangor UK, University of Wageningen, og Københavns Universitet, som har arbejdet sammen med nationale forskningsinstitutioner i Mali, Niger, og Burkina Faso. Formålet har været at forbedre lokalbefolkningens livsgrundlag på kort og lang sigt gennem forædling og genbevaring af fire meget vigtige Sahel arter (*Tamarindus indica*, *Adansonia digitata*, *Ziziphus mauritiana* and *Parkia biglobosa*). Mere konkret har formålet været at øge forståelsen af arternes genetik med henblik på at styrke forvaltning og bevaring af arternes genetiske ressourcer.

Denne afhandling bidrager til ovennævnte formål for *Parkia biglobosa*'s vedkommende ved at:

- Sammenligne hvordan forskellige oprindelser (provenienser) har udviklet sig i etableret feltforsøg
- Benytte DNA markører og bladmorfologi i kombination til at undersøge den genetiske struktur af *P. biglobosa* i den naturlige udbredelsesområde i West og Central Afrika
- Undersøge om der er forskelle i fænologi mellem forskellige *P. biglobosa* oprindelsers, og om sådanne forskelle i givet fald udviser et geografisk eller økologisk mønster.
- Diskutere en strategi for hvordan genetiske ressourcer af *P. biglobosa* (Jacq.) Benth kan bevares og udnyttes i Burkina Faso.

Studierne i punkterne 1 og 3 er baseret på målinger og registreringer ved forskellige alder i to international proveniensforsøg lokaliseret i hhv en nordlige sudano zone (Gonse) og den sydlige sudano zone (Dinderesso) i Burkina Faso. Der indgår tilsammen 25 forskellige provenienser (oprindelser) i forsøgene, og analyse af resultaterne afslører en betydelig genetisk differentiering mellem provenienserne. Træernes overlevelse, vækst, bladmorfologi og –fænologi afhænger således af deres oprindelse. Resultaterne underbygger en hypotese om, at *P. biglobosa* som art består af et kontinuum af mere eller mindre lokalt tilpassede oprindelser, og dette kan være en delvis forklaring af hvordan arten evner at vokse naturligt på lokaliteter over en markant økologisk gradient. Det vil imidlertid være nødvendigt at udføre reciproke forsøg for at kunne påvise lokal tilpasning, og det anbefales at lave sådanne forsøg. Betydning af disse observationer i forhold til både genetisk bevaring, udvikling af nye frøplantager og frøkildevælg og i plantningsprogrammer diskuteres i afhandlingen.

Studiet af genetisk struktur (punkt 2) er baseret på analyser af blade samlet fra træer i de to ovennævnte forsøg. Analyserne baseret på både DNA af bladmorfologi underbygger at der er tale om betydelig genetisk differentiering mellem *P. biglobosa* bestande indenfor udbredelsesområdet, og at der disse forskelle som bør inddrages i forvaltning af artens genetiske ressourcer, og her kan det konstruerede haplotype kort være værdifuldt. De betydelige forskelle i bladmorfologi er særligt bemærkelsesværdige, men det lykkedes ikke i nærværende undersøgelse at finde en simple sammenhæng med vækstvilkår på proveniensernes oprindelsessteder. Derimod kan observeres en tydelig øst-vest gradient.

I den sidste del af afhandlingen beskrives og diskuteres en plan for udvikling af de genetiske ressourcer af *P. biglobosa* i Burkina Faso gennem målrettet domesticering. Der udvikles en plan baseret på det såkaldte Breed Seed Orchard (BSO) koncept. Det beskrives hvordan plustræer er blevet udvalgt og karakteriseret i programmet, og resultater fra dette store feltarbejde præsenteres. Det beskrives hvorledes der er anlagt BSO'er er blevet anlagt, og der fremlægges og argumenteres for de næste skridt i dette arbejde. De første, foreløbige resultater fra vækst i BSO præsenteres og diskuteres som input til det fremadrettede arbejde. Allerede på det tidlige stadium kan observeres vigtige forskelle mellem familier og oprindelser, som underbygger at den valgte strategi kan bidrage til værdifulde gevinster.

Afhandlingen afsluttes med en diskussion af perspektiver i fremtidige studier og mulighederne for at videreudvikle domesticerings ideerne fra Burkian Faso i et regionalt regi

INTRODUCTION

A central place of trees for the farmers' livelihoods in the Sahel.

The Sahel is a transition area between the very dry north and the tropical forests on the coast. This region is a belt extending across Mauritania, Senegal, Mali, Burkina Faso, and Niger. It is characterized by high temperatures throughout the year, with a very irregular and unpredictable rainfall pattern (300–1000 mm/year), occurring during a 3-4 months period and a 8-9 months dry season. The area is singularly characterized by frequent droughts. More than half of the inhabitants are farmers and agriculture contributes more than 40% to the Gross Domestic Product (GDP) in most of the sahelian countries. Poverty is prevalent and population growth rates at 3% per annum exceed food production growth rates of only 2% per annum (UNDP, 2003). The traditional Parkland system (integrated crop-tree-livestock systems), which is the predominant land use system in the Sahel is the main provider of food, income, and environmental services (Bonkougou *et al.* 1997; Boffa 1999; Nikiema 1993). In the Parkland system, trees play a crucial role in tempering the effects of climate, while also providing shade to facilitate the growth of crops on farms and of pastures on rangelands, in addition to providing a wide range of products (Teklehaimanot 2004; Bayala *et al.* 2002). Indigenous fruit trees, in particular in this region, play an important nutritional role as a source of micro-nutrients and vitamins to augment the diets of local people (Saka *et al.* 2002; 2004/b; Akinnifesi *et al.* 2004a). The fruits of many of these species are important as a source of diverse nutritious elements and income during the late dry season and early wet season, when stocks of cereal crops are usually low (Ky 1994; Ouedraogo 1995; Simons 1996; Akinnifesi *et al.* 2006; Kalinganire *et al.* 2008; Lamien 2007; Teklehaimanot 2008).

Despite their crucial importance, over the last 20 to 30 years the Parklands are rapidly degrading, the richness and abundance of agroforestry trees and shrubs is being lost (Atta-Krah *et al.* 2004; Nikiema 2005), and soil fertility is declining from already low levels through exhaustive cropping practices and soil erosion (Catino 1988; Nikiema *et al.* 1993; Eyog Matig and Ouedraogo 1999; FAO 2000). Less species richness means fewer distinct sources of products and services and lower abundance means less genetic variation within species, which reduces both the capacity of trees and shrubs to adapt to environmental change and the potential gain that farmers can realize from selection (Kalinganire *et al.* 2008). Therefore, there is an urgent need to restore and protect the Sahelian Parklands for the future welfare of over 400 million people living in the semi-arid drylands of West Africa.

In the Sahel, during the last 30 years, substantial tree-planting operations have been carried out (Nikiema 1993) which aim in addition to their primary objective of wood energy production, to contribute to water conservation, to soil erosion and desertification control. Particularly, in Burkina Faso, village woodlots have been planted and there have been several national schemes, including the National Village Forestry Programme and, later, the campaign entitled “8000 Villages, 8000 Forests” (MEE, 1996). Millions of seedlings have been planted but the results did not live up to expectations. There are many reasons for this lack of success and in addition to silvicultural constraints, the poor genetic quality of the material used is an important factor (Ræbild *et al.* 2004).

Domestication as a tool to mitigate the risk of decreasing adaptive potential of trees in the parkland systems and improvement of the quality of their products.

One of the solutions to the problems mentioned above is the improvement of agriculture by domesticating indigenous fruit trees of economic value (Leakey 1999; Teklehaimanot 2004; Kalinganire *et al.* 2008; Leakey *et al.* 2012). Domesticating indigenous fruit trees is a tool to unlock the potentials of genetic materials and indigenous knowledge in rural communities (Akinnifesi *et al.*

2008). Therefore, domesticating and cultivating the priority indigenous trees on farms will contribute to food security, to higher export earnings and to sustainable and productive dryland agriculture (Teklehaimanot 2008).

P. biglobosa was among the top five priority indigenous tree species identified during the farmers' priority-setting exercise carried out by ICRAF (Bonkougou *et al.* 1998). This is mainly due to its socio-economic importance (Ky 1994; Ouedraogo 1995; Nikiema 1993; Teklehaimanot 2004; Lamien *et al.* 2008). The species is one of the priority research species in Burkina Faso and several investigations have been done since the 1980's (Ouedraogo 1995, Sina 2006).

Raebild *et al.* (2011) reviewed the domestication status and pointed out that the major achievements in the species' domestication are: the initiation of a pan african germplasm collection of the species, the initiation of eco-physiological stress studies, the investigation of vitamin and nutritional values, molecular marker studies of several origins, the success of grafting and other vegetative propagation techniques. Raebild *et al.* (2011) therefore suggest that future research may be focused on: optimization of grafting techniques, micro-propagation techniques, study of the relationship between morpho-types and genotypes, the study of genetic parameters for fruit production and the incompatibility systems in the species pollination test

Taxonomy, Distribution, and genetics of the Parkia biglobosa

The genus *Parkia* belongs to the family of Leguminosae, sub-family Mimosaceae and contains 31 species, which are distributed throughout both the New World and Old World tropics (Luckow & Hopkins 1995). The centre of taxonomically diversity is in the rainforests of the Amazon Basin (Hopkins 1986), while about 10 species are distributed in the Indo-Pacific region (Hopkins, 1994), 1 species in Madagascar and 3 species in Africa (Hopkins 1983). The 3 species found in Africa are distributed in several phytogeographic zones. Two species are mainly found in wet forest types: *Parkia filicoidea* and *Parkia bicolor* while *Parkia biglobosa* is mainly found in the savanna. There are transitions areas with potential overlap between species of the same genus. Their ability to hybridise in areas with overlapping distribution has not been investigated, but the species are reported to have the same number of chromosomes. Most of the *Parkia* species studied are reported to be bat-pollinated (Hopkins 1983).

Compared to the distribution of the two others species of *Parkia* found in Africa, *P. biglobosa* (Jacq.) Benth, named after Mungo Park by Robert Brown (1826), is the most northern. The height of the tree ranges from 10 m to 20 m with a very wide spreading umbrella- shaped crown extending outwards from the bole by as much as 10 m (Ouedraogo 1995).

The natural range of *P. biglobosa* extends over 19 African countries from Senegal in the west to Uganda in the east (Hall *et al.* 1997): Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Cote d'Ivoire, Democratic Republic of Congo, Gambia, Ghana, Guinea, Guinea-Bissau, Mali, Niger, Nigeria, Sao Tome et Principe, Senegal, Sierra Leone, Togo, and Uganda. *P. biglobosa* occurs in a wide range of natural and semi-natural communities such as open savannah woodlands, but it is most conspicuous and abundant in anthropic communities, principally bush fallow and wooded farmland where cultivation is semi-permanent. The tree can also grow on rocky slopes, stony ridges or sandstone hills (Hall *et al.* 1997). *P. biglobosa* occurs in a diversity of agroecological zones, ranging from tropical forests with high and well-distributed rainfall to arid zones where mean annual rainfall may be less than 400 mm. It has a capacity to withstand drought conditions because of its deep taproot system and an ability to restrict transpiration (Bouda *et al.* 2013).

Socioeconomic potentials

P. biglobosa, commonly named Néré or African locust bean, is highly valued for its brown seeds that are ground into a pungent nutritious spice or condiment, soumbala or dawadawa, which is added to soups and stews throughout the savanna regions of sub-Saharan Africa (Campbell-Platt 1980; Ky 1994; Ouedraogo 1995; Lamien *et al.* 2011).

P. biglobosa' seeds provide an important source of protein and the fermented seeds (soumbala or dawadawa) have often been referred to as a cheese substitute (Booth and Wickens 1988). The pulp also has considerable nutritional value, and is rich in sugars (Ouedraogo 1995). It is used to make drinks and couscous, particularly during the dry season period.

P. biglobosa fruit is a major commodity of local and regional trade in sub-Saharan Africa. In Burkina Faso, néré fruits are highly commercialized, with over 50% of respondents in a nation wide survey participating in trade (Teklehaimanot 1997). The seeds of *P. biglobosa* may be sold for commercial processing or bought by women traders who cook and ferment them for sale in the markets.

In Nigeria, 100 kg of dried seed was sold on average for approximately 2000 Naira (US\$1= 21 Naira in 1994). On average the cost of 50 g of processed néré varied between 1.5 and 2 Naira; thus there was a doubling in price compared with the unprocessed seeds (Hall *et al.* 1997).

It was the same in Burkina Faso where the price of dried seeds varied between 100 and 300 FCFA kg⁻¹, while the price of fermented seeds was between 300 and 650 FCFA kg⁻¹ (US\$1=450 FCFA). The revenue earned per annum from the sale of néré products in Burkina Faso is approximately 27300 FCFA per household. This constitutes 28.8% of the income per household (Nikiema 2005).

Human medicine

Human medicine is one of the chief uses of *P. biglobosa* and nearly all parts of the plant are used as a cure against a large range of human ailments, especially piles, malaria and stomach disorders. The bark is the part most commonly used in the treatment of digestive ailments, followed by roots, leaves, exocarp and pulp (Ky 1994; Ouedraogo 1995). The seeds appear to be important in the treatment of blood disorders, whereas extracts from the leaves are used in alleviating skin disorders. The pulp, the seeds and the leaves are most often used in the treatment of jaundice and similar other ailments. The bark, the roots and the fruit appear to have similar properties, as they are the most often used parts in the treatment of wounds and gangrene. In general, the roots are only used when a strong dose of medicine is required. Soumbala is most often used in the treatment of nervous system disorders (Ouedraogo 1995; Hall *et al.* 1997; Teklehaimanot 1997).

P. biglobosa is also important both in agriculture and raising livestock. The exocarp, the leaves, and the seed coats are all used for fertilizer.

P. biglobosa is often traditionally used in ceremonies connected with virility, pregnancy, birth, circumcision, wedding, death, funeral and spiritual protection.

Status and perspectives of P. biglobosa's genetic resources investigation in Burkina Faso

Despite of the urgent need of domesticating such important tree species like *P. biglobosa*, the development of national tree improvement programmes in the tropics is still in its infancy, in particular for multipurpose species (Palmberg 1986; Graudal and Kjær 1999; Leakey *et al.* 2012). Indeed most of the breeding activities in the Sahel are mainly originating from research projects which are characterized by unstable resources available for long term work. Specifically, in Burkina Faso, *P.*

biglobosa's breeding and conservation activities were financed sporadically by two research projects in 1993 (EU-INCO research contract TS3*-CT92-0072, 1993-97) and 1998 (EU-INCO research contract no IC18-CT98-0261). The present work is also financed by a research project and it is about breeding and conservation of genetic resources of *P. biglobosa* in the West African Sahel. It has the ambition to strengthen the tree improvement programme of the species outlined by precursory studies (Ouedraogo 1995; Sina 2006).

OBJECTIVES

The overall purpose of this thesis is to contribute to the sustainable livelihood for local people in the sahelian region through improvement and conservation of *P. biglobosa*.

The objectives of the present research project were to strengthen the existing knowledge on the genetic structure of *P. biglobosa* in its natural distribution area in Africa and develop strategies for breeding and conservation of the species.

More specifically, the objective of the research is to improve the genetic knowledge base on *P. biglobosa* with relation to management of genetic resources in three aspects:

- ✓ to study performance of provenances in existing experiments in order to provide information that can guide conservation and deployment strategies for the species in Burkina Faso;
- ✓ to quantify and discuss genetic demographic parameters that can support a knowledge based strategy for establishment and management suitable seed source;
- ✓ to determine the suitability of different traits in relation to operational improvement.

METHODS AND RESULTS

The following sections describe the objectives of each of the four papers produced in the PhD research project, the materials and method, and the results achieved.

Paper I. Evidence for important genetic differentiation between provenances of *Parkia biglobosa* from the Sudano-Sahelian zone of West Africa

(Published paper in Agroforestry System DOI 10.1007/s10457-011-9463-7)

In this paper, a range wide sample of provenances of *P. biglobosa* was tested in Burkina Faso, West Africa at two sites, Gonse (latitude 12°25'N; longitude 1°20'W; altitude 280 m) in the North-Sudanian zone (fig. 1.) and Dinderesso (latitude 11°18'N; longitude 4°35'W; altitude 425 m) in the south-sudanian zone.

In total, 25 provenances from 11 West and Central African countries were used to establish the two experiments. Each trial includes 15 provenances of which five are tested in both trials.

The main objectives of the present paper is to evaluate the outcome of these field trials by testing if growth and survival vary significantly among provenances, and to what extent such variation reflects geographic and/or climatic factors.

Conclusion and perspectives

Substantial genetic differentiation was observed among the natural populations of *P. biglobosa* in West Africa for most of the growth traits and survival. The significant differences among populations found in survival and in vigour (fig.2.) could partly be described by geographic and ecological clines supporting the hypothesis that the gene pool of *P. biglobosa* in West Africa is differentiated according to climate conditions. This has important implications for gene conservation, seed procurement and design of domestication programmes as discussed in paper IV below.



Fig.1 a general view of the provenances trials at Gonsé at age 13.

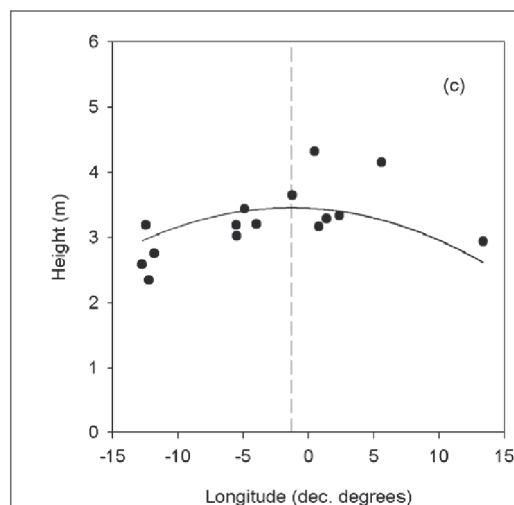


Fig. 2. Regressions of height growth with longitude at Dinderesso site, Burkina Faso.

Paper II Morphological differentiation of *Parkia biglobosa* leaves across West-Africa: adaptation to local climate or a legacy of past dynamics in species' distribution?
(Submitted to x)

Paper II addresses the same two transplanting experiments of *P. biglobosa* (cf. paper I) with the aim to study genetic divergence among populations using particularly leaf traits and neutral markers. We investigate if patterns of variation in putatively adaptive traits reflect climatic adaptation. As an alternative hypothesis, we consider the possibility that the observed geographic pattern is the result of the evolutionary history of the species.

Therefore, a biometric study of nine leaf characters was carried out on a sample containing leaves from 12 trees from each of 15 populations. Leaves were collected in the experiment at age 13 years. Data was analysed using uni- and multivariate statistical methods to study the relation to geographic and climatic descriptive variables.

In addition, cpDNA variation was examined in samples of three to five individuals from 24

populations by sequencing of two introns. A haplotype network was constructed, and phylogeographic structure was studied by plotting haplotypes by geographic origin.

Results

Significant clinal variation relating to longitudinal origin was found for six of the studied leaf morphological traits (fig.3). Canonical variate analysis confirmed the strong correlation between longitude and morphological traits, as populations could be plotted in an informative way in only one dimension. None of the traits analysed showed significant correlation with latitude or climatic variables.

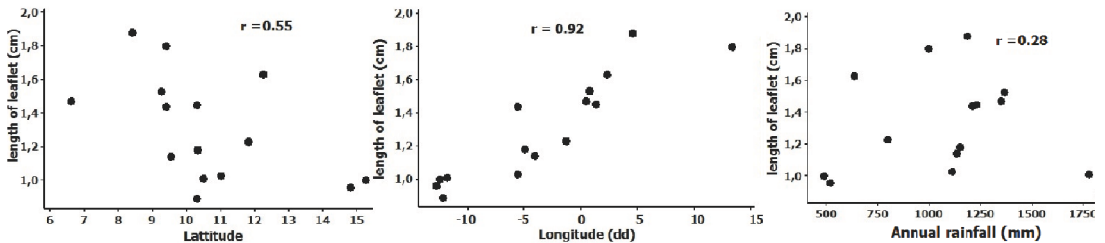


Fig.3. Correlation between the length of leaflet and geographic and climatic variates

The DNA sequence analysis revealed a strong phylogeographical structuring with the seven identified haplotypes being divided into an eastern and a western group. The haplotype network indicated that the species originated or had a refugium in central West Africa.

Main conclusions

From the joint analysis of morphological and neutral markers of genetic variation we suggest vicariance to be the source of the observed variation in the species. Strong geographic affiliation of the haplotypes suggests that humans have played only a minor role in forming the present day distribution of the species. It is speculated that past climate regime of the region could explain the morphological variation observed.

Paper III. Variation in timing of Phenological traits of 15 West and Central African provenances of *Parkia biglobosa* (Jacq.) Benth in the south sudanian zone of Burkina Faso (Manuscript)

Paper III, addresses the provenances experiment of *P. biglobosa* located in the south Sudanian zone in Dinderesso (latitude 11°18'N; longitude 4°35'W; altitude 425 m), western Burkina Faso, in order to investigate the flushing, the flowering and the fruiting phenology of the species at age 14 years.

The aim was to study the genetic variability in relation with phenological traits within and among the West African provenances of *P. biglobosa* and to draw breeding and conservation strategies based on the knowledge obtained from the study.

Results

Significant genetic variation was found to be significant among provenances for different phenological traits (beginning of flushing, the leaf senescence, the flushing peak). Correlations were found to be

significant between some of the phenological traits (beginning of flushing, the flushing peak, the flushing end) with the geographical parameters (latitude, altitude) of the provenances and some of the climatic variables (annual mean temperature, the length of the humid season).

Conclusion

These variations observed in phenological traits suggest that attention has to be paid by breeders and silviculturalists in the choice of the provenances when establishing seed orchards and plantations of *P. biglobosa* in order to chose provenances which could interpollinate.



Fig.4. Capitulum flowering phases of *Parkia biglobosa* (start of flowering to flowering end)



Fig.5. Capitulum fruiting phases of *Parkia biglobosa* (fruiting start to end).

Paper IV. Mobilisation and characterisation of *Parkia biglobosa* (Jacq.) Benth genetic resources for domestication and conservation in Burkina (Manuscript)

Paper IV, addresses the selection process within the distribution area of the species in Burkina Faso, West Africa with the aim to constitute a germplasm for the breeding and the conservation programme.

In each natural selected stand, the tree vigour characteristics and several numbers of fruiting traits (fruit traits, seed traits) were taken from selected plus trees.

Results

In all, 58 plus trees has been selected from 19 natural populations at the farmer' field level (fig.6.). High significant differentiation was found in many of the fruiting traits (fruits and seeds).



Fig.6. fruit collection and tree characteristic measurement in *Parkia biglobosa* natural stands in a parkland.



Fig.7. variation in pod number and morphology observed within selected trees

Significant correlation were found between the fruit traits and regression analysis confirmed that indirect selection for seed high yielding trees could done based on the pod morphological traits (fig.7).

Multivariate analysis revealed high significant differences among provenances and permit to confirm that the east-west cline variation observed through the species distribution area in Africa (paper II) could be observed in fine scale at country level in some of the leaf characteristics observed on the seedlings of *P. biglobosa*.

Conclusions

This study provides basic information for the development of a breeding population for a *P. biglobosa* tree improvement program. The number of the selected populations and plus trees included in the selection process and the involvement of the farmers at different steps of the breeding activities constitute a substantial pledge of a real integration of both breeding and germplasm conservation activities of the species.

GENERAL CONCLUSIONS AND PERSPECTIVES

The present work supports the increasing body of studies that report substantial provenance variation of dry zones species in Africa for tree improvement activities (Wolde-Meskel and Sinclair 2000; Raebild *et al.* 2003a,b,c,d; Weber *et al.* 2008; Bayala *et al.* 2009; Larwanou *et al.* 2010). Ræbild *et al.* (2011) reviewed an ongoing domestication research of some of the most important indigenous species of dry West Africa (*Adansonia digitata*, *Parkia biglobosa*, *Tamarindus indica*, *Vitellaria paradoxa* and *Ziziphus mauritiana*). The findings of the present thesis confirm that large provenance variation is present among different origins of *P. biglobosa* in the West African Sahel, and details the genetic structure across the West African distribution area. The high genetic diversity revealed among and within West African populations of the species indicates that there is no immediate risk of genetic erosion in this region, as long as ecological conditions continue to permit regeneration. However, the results provide strong indications of phenological differentiation likely to reflect local adaptation, and thereby flag the risk of populations becoming less adapted if global warming changes climatic conditions dramatically. The thesis provides examples of how this information can be transferred into breeding activities at a national or regional level, and can therefore hopefully provide some guidance for tree breeders, silviculturalists and policy makers for long and efficient utilization of *P. biglobosa* resources in the Sahel.

Although the present studies have provided unique data on the variation between populations, it must still be seen as a pilot phase in terms of pre-breeding activities. Studies based on additional sites and including more provenances are needed to confirm the results obtained from the present study. To strengthen the breeding and conservation programme of *P. biglobosa*, future research could be focused on determining how far *P. biglobosa* seed could be transferred as part of a human assisted migration strategy in face of the on-going climate change. A specific program for *ex situ* conservation of northern populations known as fragmented seems especially important as the unique gene pool that these stands represent may be lost if the northern distribution limit of *P. biglobosa* shifts southwards. Studies in clonal trials in various agro-ecological zones and in the species' pests and diseases are also important areas of research.

Several research questions remain unresolved in relation to the landscape management of the genetic resources of the species. In order to understand the nature and the background for the observed genetic pattern, a combination of ecophysiological investigation, and gene flow studies in various ecological conditions have to be conducted in order to provide new insight into the dynamics of *P. biglobosa*'s population in the region. Fortunately, some of the above suggested studies are in progress and could help strengthen the findings of the present work.

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Chapter 2 Evidence for important genetic differentiation between provenances of *Parkia biglobosa* from the Sudano-Sahelian zone of West Africa

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Chapter 3 Morphological differentiation of *Parkia biglobosa* leaves across West Africa: adaptation to local climate or a legacy of past dynamics in species distribution?

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Chapter 6 Variation in timing of Phenological traits of 15 West and Central African provenances of *Parkia biglobosa* (Jacq.) Benth in the south sudanian zone of Burkina Faso

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Chapter 5 Mobilization and characterization of *Parkia biglobosa* (Jacq.) Benth genetic resources for domestication and conservation in Burkina Faso.

Manuscript

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Improving and conserving sahelian fruits trees:
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